Physics of *Tanpura*: Some Investigations

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Tanpura is a four-stringed instrument mainly used in Indian classical music. The four strings are tuned to P̣a (Pa in lower octave) Sa, Sa, and Ṣa (Sa in lower octave). The strings are plucked in the same order P̣a, Sa, Sa, Ṣa at such a rate that the tones of successive strings overlap and give rise to combination tones. The drone of a *tanpura* consists of: (i) the fundamental notes or the primes, (ii) the harmonics and (iii) the combination tones. Accompaniment of *tanpura* drone helps the singer to remain in tune with the notes of the scale used.

The quality of a tone produced by a musical instrument depends upon the nature of vibration of the sound-producing object such as reed, string etc. and also on the frequency response of the sounding-board.

Nature of Vibration of a *Tanpura* String

The bridge on the board of a *tanpura* resonator (gourd) is wide and curved. It is made of ivory or sissoo wood. The strings pass over the arched bridge tangentially. A piece of cotton thread called *juari* or *jeeva* is placed under each string. Proper placement of the *juari* is necessary for producing characteristic *tanpura* tone (Figure 1). In this position of the *juari*, the string just touches (or is just above) the bridge surface, so that during vibration, the string gets lifted* up in its upward motion and touches the bridge at the point of contact (Figure 1) during its downward motion. The string thus strikes the bridge periodically in the course of its vibration. Further, during the upward motion of the string, the end nodal point suddenly jumps from the point of contact to *juari* position and during the downward motion the nodal point jumps back to the point of contact and slightly drifts towards the left (Figure 1). Using a magnifying glass and strobe light one can see, in slow motion, the string leaving the bridge at the point of contact and returning to it periodically. One such slow motion video recording has been made at N.C.P.A.

* Lifting up of the string from the bridge has been noted by Dr. B. C. Deva.

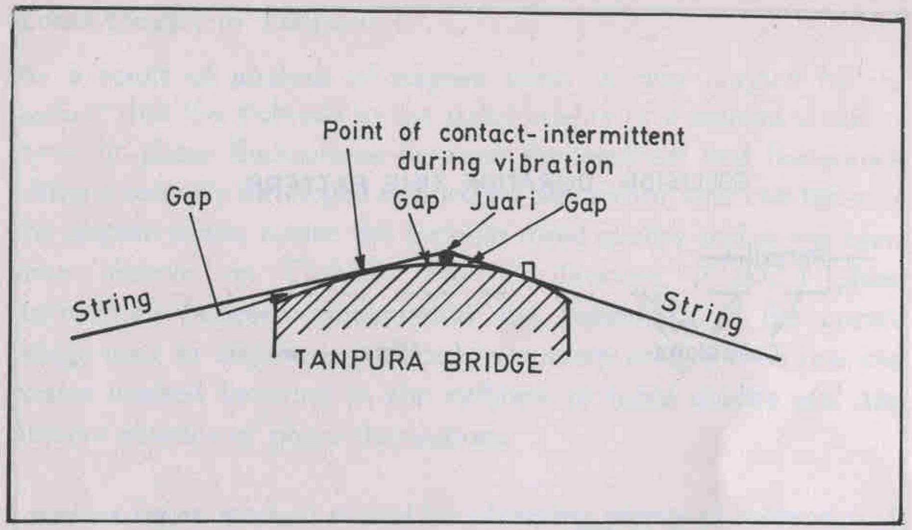

Figure 1

The encounters between the string and the bridge surface are, however, not simple comprising of just one collision per cycle, as was thought by Dr. B. C. Deva.[1]

Collisions of the string with the bridge generate harmonics in the string and the string starts "quiverring". Initially when the amplitude is large, contact (with the bridge) and no-contact timings during collision are equal. But soon after, as the amplitude of the string decreases, the collisions split up into four, then three, then two and finally one interval of shorter duration. Collision duration time-pattern is shown in Figure 2. Each pattern repeats a few times and is followed by the next pattern. A video recording of collision duration time-pattern has been made at N.C.P.A.

The above explained nature of vibration of the *tanpura* string explains musicians' observations[2] namely (i) the decay of harmonics

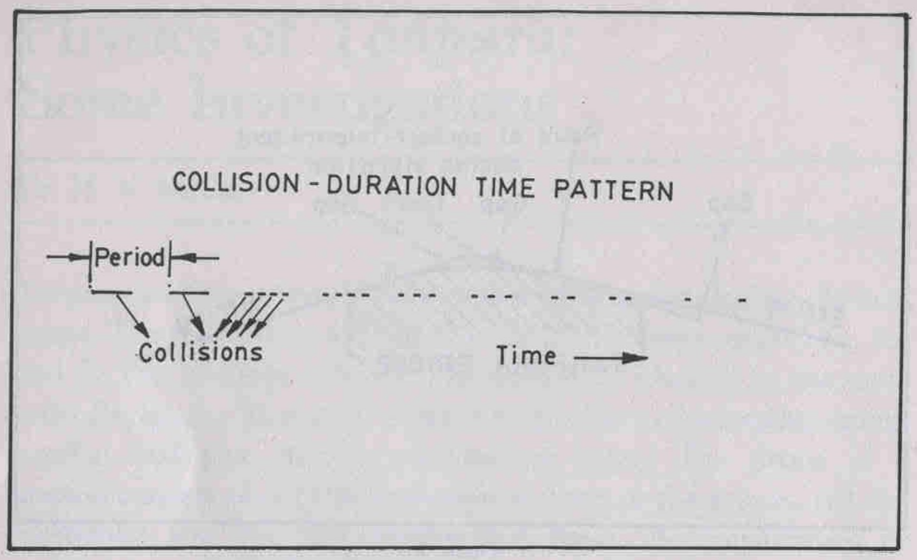

Figure 2

is slower compared to the decay of the fundamental and (ii) some of the harmonics start building up again during the course of vibration of the string.

In case of a string stretched on sharp bridges, harmonics requiring a node at the point of plucking are absent. But in case of a *tanpura*, such harmonics do exist. This has been explained by C. V. Raman[3] by periodic variation of the contact point between the string and the curved bridge.

Figure 3 shows a typical *frequency response curve* of a *tanpura* sounding-board. This curve was obtained by injecting air vibrations of constant amplitude in the cavity of the *tanpura* sounding-board through a small hole on the top plate near the bridge, and measuring sounding-board vibrations using a contact microphone. The frequency response modifies the proportion of harmonics produced by the string. Harmonics coinciding with the resonance frequencies (formants) of the sounding-board are reproduced with greater intensity compared to other harmonics.

Tonal Quality of *Tanpura*

As a result of analysis of *tanpura* tones, it was noticed by the author[4] that the richness in the tonal quality of a *tanpura* is due to constant phase fluctuations between fundamental and harmonics. Using a recently developed method by the author, one can listen to the *tanpura* tones, notice the peculiar tonal quality and at the same time observe on Cathode Ray Oscilloscope (C.R.O.) phase fluctuations between fundamental and harmonics. If the curved bridge used in *tanpura* is replaced by a sharp bridge, then one can notice marked lowering in the richness of tonal quality and also observe absence of phase fluctuations.

Lissajous figure method is used for observing phases of harmonics. If a particle is acted on by a sinusoidally varying force in 'X' direction,

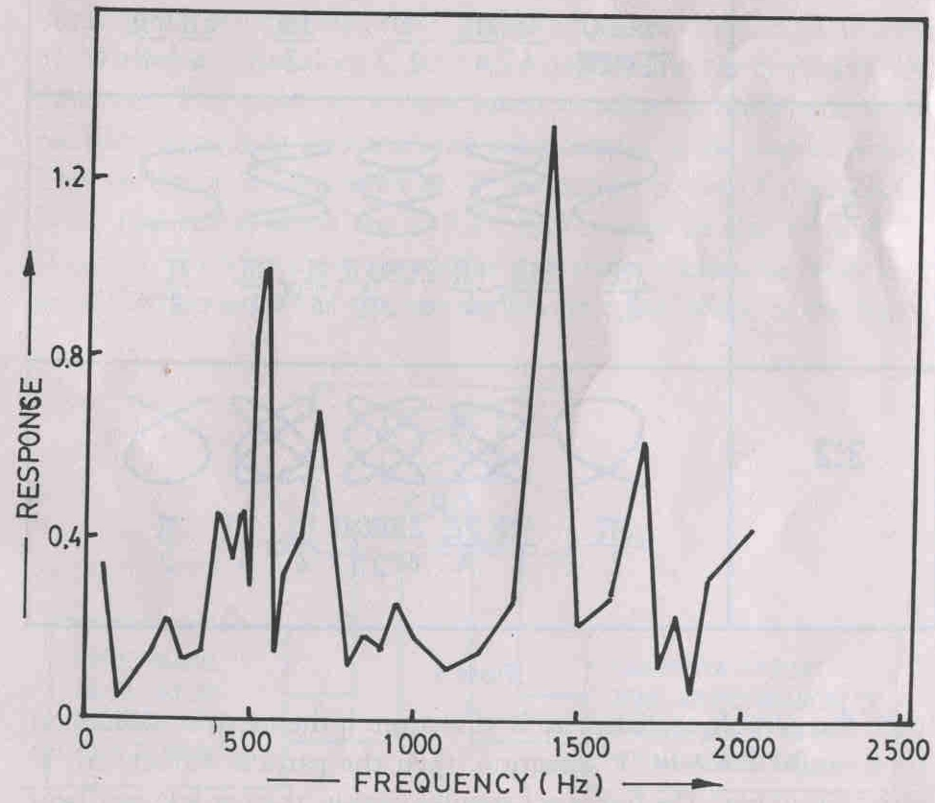

Figure 3: Frequency Response Curve of a Tanpura Sounding-Board

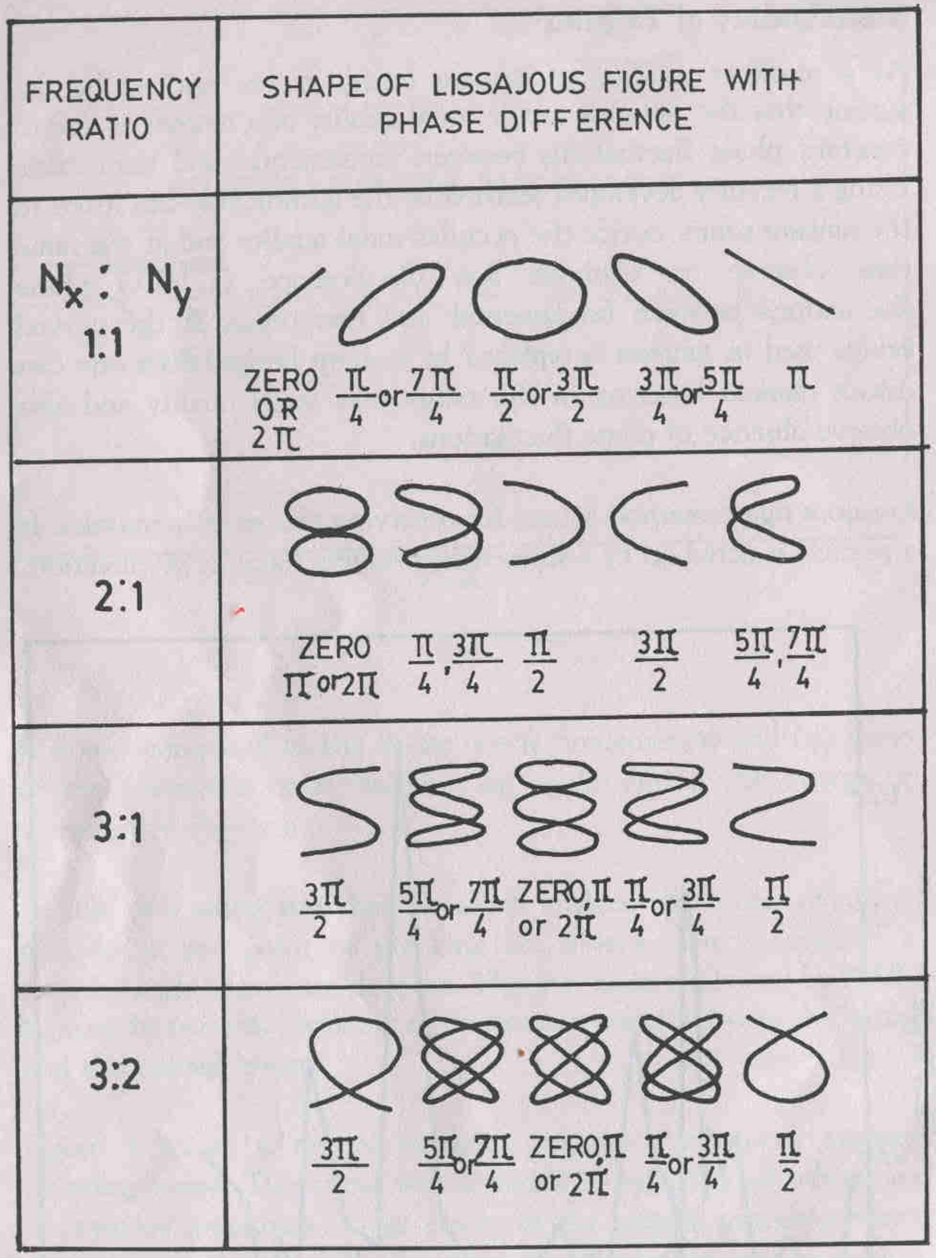

Figure 4

then the particle oscillates in 'X' direction. If the particle is acted on by a similar force in 'Y' direction, then the particle vibrates in 'Y' direction. If both the forces act simultaneously, the particle oscillates along a curve, shape of which depends upon the frequency ratio of the two oscillations, their relative amplitudes and also on the relative phase between the two oscillatory motions. Figures traced by the particle are known as Lissajous figures. The figures have a simple shape when the frequency ratios are simple. Figure 4 shows Lissajous figures for four different frequency ratios 1 : 1, 2 : 1, 3 : 1 and 3 : 2 for different relative phase angles, but nearly equal amplitudes.

Experimental Procedure for Observing Phase Fluctuations of the Fundamental and Harmonics of a *Tanpura* Tone

(I) One of the *tanpura* strings, (with a *juari*) under investigation, is tuned to its usual note by a musician. Vibrations of the plucked string are converted into corresponding electrical variations by a suitable electromagnetic pick-up. The electrical variations are amplified and electronically filtered to give sinusoidal output of fundamental frequency of the *tanpura* string. This extracted fundamental is connected to 'X' deflection plates of a C.R.O. (Figure 5). With this signal alone C.R.O. spot oscillates in the horizontal 'X' direction. The musician is then asked to adjust a stable sine wave oscillator exactly in tune with the fundamental of the *tanpura* string. This oscillator is connected to 'Y' deflection plates of the C.R.O. With this signal alone the C.R.O. spot swings in the vertical 'Y' direction. With both the signals the spot traces a Lissajous figure and since the frequencies of the two signals are equal, shape of the figure

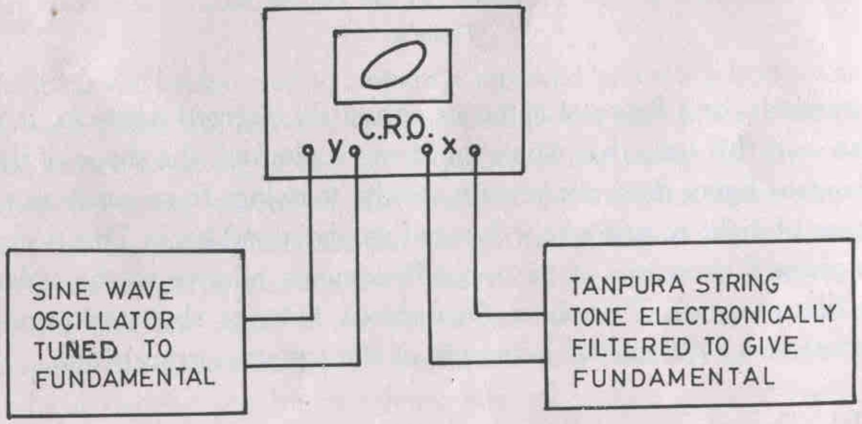

Figure 5

is a straight line or an ellipse or a circle. It is, however, observed that the shape of the Lissajous figure does not remain the same during the course of vibration of the string. The changes in the shape of the figure (line to ellipse to circle and back) indicate phase fluctuations of the fundamental relative to steady oscillator signal. The phase fluctuations are due to slight variations in the fundamental frequency of the *tanpura* string.

(II) The experimental arrangement is then slightly modified as shown in Figure 6. This time the electronic filter is tuned to give second harmonic output. Repeating the procedure, as explained above, a Lissajous figure is obtained on the C.R.O. screen. Since the frequency ratio this time is 2 : 1 the shape of the Lissajous figure is

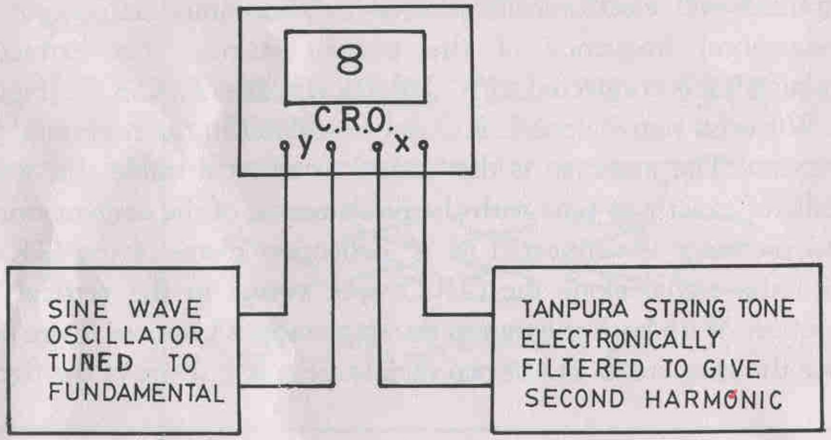

Figure 6

a parabola, or a figure of eight, or oppositely directed parabola. It is also seen this time that when the string is plucked, the shape of the Lissajous figure does not remain steady, it swings from parabola to figure of eight to oppositely directed parabola and back. This is due to phase fluctuations of the second harmonic relative to the stable oscillator signal. The phase fluctuations indicate slight frequency variations of the second harmonic of the *tanpura* (string) tone.

(III) The sine wave oscillator is now removed, instead the fundamental and the second harmonic are simultaneously extracted using two electronic filters as before. The outputs of these filters are applied to the C.R.O. as shown in Figure 7. Since the ratio of the two frequencies is 2 : 1, the shape of the Lissajous figure is a parabola or a figure of eight or oppositely directed parabola.

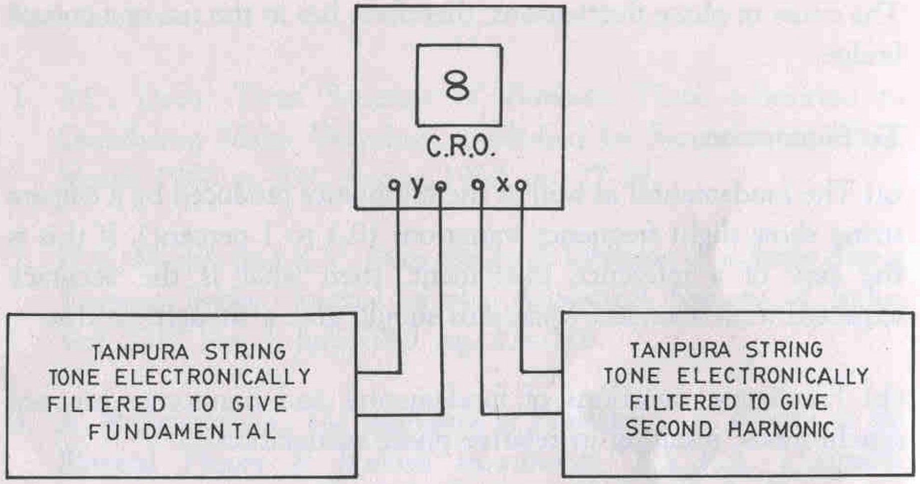

Figure 7

The shape of the figure this time also does not remain steady during the course of vibration of the string. The figure swings from one shape to the other. This is due to phase fluctuations of the second harmonic relative to fundamental and indicate that frequency variations of the fundamental and second harmonic are not synchronous. Similar results are obtained for higher harmonics also.

If the curved bridge used in *tanpura* is replaced by a sharp bridge then no such phase fluctuations, as described above, take place. One can also notice lowering of the tonal quality of the string. In this case, when the string is plucked, the shape of the Lissajous figure almost remains unchanged but only the size of the figure goes on decreasing with the decaying amplitude of the vibrating string. It, therefore, follows that the cause of the phase fluctuation lies in the peculiar shape of the curved bridge. Phase fluctuations between fundamental and the second (or higher) harmonic take place even if *juari* is removed. The only difference is that when the *juari* is not used, the phase changes are slow resulting in slow variations in the shape of

Lissajous figure. *Tanpura* tone becomes richer in harmonics when the *juari* is used. Use of *juari* reduces the duration of vibration of the string and, therefore, with the use of *juari*, changes in Lissajous figures take place rapidly.

The cause of phase fluctuations, therefore, lies in the use of a curved bridge.

To Summarise

(a) The fundamental as well as the harmonics produced by a *tanpura* string show slight frequency variations (0.5 to 1 percent). If this is the case of a reference instrument, then what is the accuracy expected from a singer? Musicians should give a thought to this.

(b) Frequency variations of fundamental and harmonics are not synchronous, resulting in relative phase modulation.

(c) This type of phase modulation is the cause of peculiar tonal quality of *tanpura*.

(d) Fourier analysis of *tanpura* tones, presently carried out with computer, is not aimed at giving information regarding phase fluctuation of harmonics relative to fundamental. The author believes that such information is necessary in describing the tonal quality of *tanpura* or of instruments like *vina* in which curved bridges are used.

(e) Tonal quality of electronic *tanpura*-s presently manufactured may be more realistic by incorporating phase fluctuations described above.

(f) Since the strings used in *tanpura* are stiff, not perfectly flexible, it may be worthwhile to examine deviations of *tanpura* harmonics, if any from ideal values.

(g) The *tanpura* drone consists of the primes or the fundamentals, the harmonics and the combination tones. We believe that the *tanpura* drone helps the singer in maintaining correct intonation. Since the frequencies of the fundamental and the harmonics are slightly fluctuating during the course of vibration, it may be worthwhile to study with precision the nature of combination tones.

References:

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3. A. Ranganathan, *The Relevance of Professor C.V. Raman to the Physical Theory of Musical Instruments*, N.C.P.A. Quarterly Journal, Vol. XII, Nos. 2 & 3 (Part One), June & September 1983, pp. 11-21.

4. H.V. Modak, *Automatic Musical Instrument in Aid of Research in Indian Music*, "Sangeet Natak"—Journal of the Sangeet Natak Akademi, New Delhi, July-September 1970, p. 91.